THE STRUCTURE OF WOOD
AND
SOME OF ITS PROPERTIES AND USES

GERRY

NORTHERN HEMLOCK AND HARDWOOD
MANUFACTURERS ASSOCIATION

Bulletin 1

R. B. GOODMAN, President
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In Co-Operation with the
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An Address Before the Members of the Northern Hemlock and Hardwood Manufacturers Association, at the Forest Products Laboratory—April 28, 1915

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By ELOISE GERRY

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THE STRUCTURE OF WOOD.

A microscopical study of wood brings out the characteristics by which different kinds of wood can be identified. It makes clear many of the reasons for the variations in the properties, both chemical and physical, and for the behavior of wood under different circumstances.

Variability of Wood.—For building purposes wood competes, for instance, with tile, brick, steel, and other inorganic compounds of a relatively homogeneous character. Wood, which is produced by the growth of living cells, shows marked variations in its structure, due to the conditions, such as abundant or scanty moisture, nutrition, or light which surround the individual plant during its formation. The variations found among different pines, oaks, and maples, are striking, but besides these variations within the genus (e.g. pine, oak, maple) these woods vary so widely from one another that each may be said to represent one of three separate groups into which all woods may be divided. (See Plates I, II, and III.)

Sapwood and Heartwood.—Besides the variations in minute structure there are in every tree two regions which differ markedly from each other. These are the sap and heartwood.

The sapwood is the layer of wood on the outer circumference of the tree just under the bark. It varies in different trees from less than one-half an inch in width, for example, in osage orange or about an inch in most oaks, to five or more inches in width in certain pines such as loblolly. The sapwood differs from the heartwood because it contains living cells and the functional elements which conduct the crude sap, that is the water and dissolved mineral salts, from the roots to the leaves. In the leaves, in the presence of the green coloring material, called chlorophyll, and sunlight this crude sap is converted into the elaborated sap which provides nourishment for the young growing tissue. The elaborated sap is conducted down the tree from the leaves through the inner layers of the bark. From here it is distributed to the growing cells, especially those in the outer sapwood.

The heartwood which occurs around the pith at the center of the tree, does not contain living cells. It is often conspicuous in contrast to the light colored sapwood by reason of its darker color, as for example in red cedar, black walnut, and ebony. It is usually more durable than the sapwood. Every year as the inner sapwood cells cease to function they add a little to the width of the heartwood at its outer limit. Therefore, as the tree grows older the amount

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of heartwood is constantly increased. The amount of sapwood remains always about the same. The sapwood is continually recruited on its outer circumference by the addition of new cells formed by the cambium or growing layer which is located between the wood and the bark. This is the layer of soft thin-walled cells which is broken when in the spring the small boy makes whistles by slipping the woody cylinder away from the bark on a willow shoot.

The Annual Rings.—In temperate climates, like that of the United States, the tree lays down a yearly increment of growth. This is produced from the cambium and forms the outermost layer of the sapwood. This addition of new material is called an annual growth ring. ("ar" Plate I, II, and III.) The age of a tree can be estimated with considerable accuracy by counting these rings.

Spring and Summerwood.—The part of the annual ring which is formed early in the season is called the springwood ("Sp" Plates I, II, III, and IV) and that which grows later the summerwood ("S" Plates I, II, III, and IV.) The trees in a temperate climate cease growing during the winter months. Springwood cells are usually larger in diameter and have thinner walls than those formed later in the year. The summerwood in red or Norway pine, for instance, is the hard, somewhat orange-colored, conspicuous portion or the "grain." (cf. Plate I, "S".)

Soft Woods and Hard Woods.—The so-called softwoods and hardwoods are not divided according to their actual hardness in all cases. Therefore, these terms which are so commonly used are not strictly accurate. For example, longleaf pine (Plate I) is harder than basswood or aspen (Plate II) but longleaf is regarded as a soft wood and basswood a hard wood in the accepted classification according to structure. Softwoods are variously known as gymnosperms, conifers, and non-porous woods. They are the woods from the needle-leaved trees which in most cases (larch and cypress excepted) are "evergreens." Plate I illustrates woods of this class. Hardwoods are known as angiosperms and porous woods, either diffuse or ring porous, according to the arrangement of the pores in the annual ring. These woods are produced by the broad-leaved trees. On the whole the softwoods have a much simpler structure than the hardwoods.

Fibers or Tracheids.—The elements of the softwoods are chiefly fiber-like cells which are called *tracheids* ("t" Plate I). These fibers are approximately 1/10 to 1/5 inches long and have tapering ends. They are practically closed cells. The sap passes from cell to cell through thin places in the cell wall which are known as *bordered pits.* The thin membranes of these have been found* in some cases to contain very minute perforations which assist in the passage of liquids through these fibers. On the whole, however, the elements of the softwoods may be said to lack the porous type of structure which assists the rapid transfer of large quantities of water, such as exists in the hardwood trees. For this reason they are called non-porous woods. The fibers of the softwoods are placed end to end in the tree. The ends, however, lap each other approxi-

*I. W. Bailey "Preservative Treatment of Wood." For Quar. Vol. XI, No. 1, March, 1913.

mately one-third of the fiber length and the fibers run parallel to the longitudinal axis of the tree. The sap in passing up a coniferous tree 200 feet in height must then traverse approximately 36—72,000 of the fibers. These elements serve two purposes, viz., to give the required mechanical strength to hold the crown of leaves up into the light and air, and also to conduct the crude sap from the roots to the leaves.

Medullary Rays.—Other important elements are the medullary rays. (See "mr" in Plates I, II, III, and IV.) These are made up of short brick-shaped cells. The rays extend from the pith to the bark and run at right angles to the longitudinal axis of the tree. In any cross sectional disc from a tree they are seen to extend from the pith to the circumference like the spokes in a wheel. The rays are much more conspicuous in such hardwoods as oak or beech where they produce the so-called "silver grain" ("mr" in Plate III) than they are in any of the soft woods. The medullary rays serve to conduct the elaborated ~~rays~~ sap inward from the inner bark to the growing portions of the sapwood.

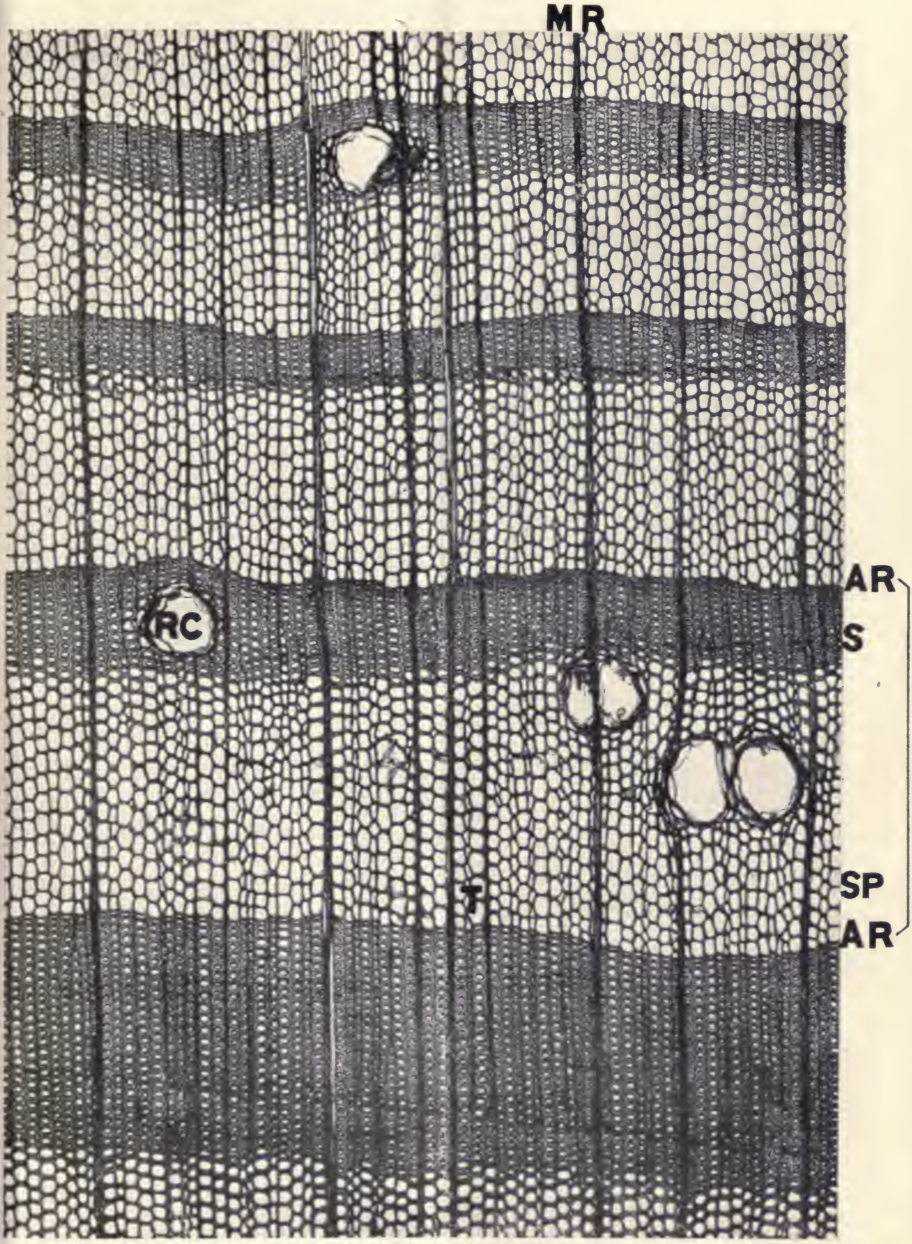
Resin Ducts.—In certain softwoods, viz., Douglas fir, spruce, larch and pine we find canals here and there among the cells. ("rc" Plate I.) These are the points in the tree where the resins or pitch, which are produced by these species, are located. They are of considerable assistance in aiding the penetrance of a wood with preservatives. They extend both vertically and horizontally through the tree. The horizontal canals are in the medullary rays and are smaller in diameter than the vertical canals. The two systems frequently connect with each other. Among the important soft woods where they are normally absent are cedar, hemlock, balsam, cypress, and redwood. The American hardwoods do not have resin ducts but in addition to the fibers and medullary rays, which are present in both hard and soft woods, they possess pores or vessels.

Pores or Vessels.—These elements are specialized channels which serve to conduct the ascending stream of the crude sap. They may be compared to the water pipes which extend from the basement to the top of a tall building. They are small hollow tubular structures. (See "v" Plates II, III, and IV.)

Diffuse Porous Woods.—If the pores are scattered with considerable uniformity through the annual ring and there is relatively little difference in size between those in the springwood and those in the summerwood, the wood is said to be diffuse porous. Maple, birch, willow, poplar, basswood, cherry, gum and tulip are examples of woods belonging to this class. (See Plate II.)

Ring Porous Woods.—When there is a considerable difference in size between the pores in the spring and those in the summerwood and the large pores are located in the springwood so that they form conspicuous concentric rings, as seen in the cross section of a log, the wood is said to be ring porous. Oak, ash, hickory, elm, catalpa, locust, mulberry, and osage orange are examples of woods belonging to this class. (See Plate III.)

In the hardwoods there is a division of labor among the elements. The fibers ("f" Plates II, III, and IV), which give the me-



ate I.—A Non-Porous Wood. Cross Section of Longleaf Pine; AR, annual ring; SP, springwood; S, dense summerwood; T, tracheids; MR, medullary rays; RC, resin canals.

chanical strength, are often thick walled. They frequently have thicker walls in proportion to the lumen or cavity enclosed than is found in the softwoods. They also share little, often not at all, in the conduction of the sap. The vessels, on the other hand, are admirably constructed to assist in the rapid transfer of considerable quantities of water solutions, since they have open porous ends which facilitate the passage of liquids with greater ease and rapidity than the tracheid type of element, where the passage always takes place through membranes, even though these may be thin and in some cases have minute perforations.

Tyloses.—In certain hardwoods, e. g. white oak, the large pores or vessels are closed more or less completely with cell-like growths called tyloses ("t" Plate IV). These in many cases render the wood practically impermeable to liquids and gases. It is because of the presence of tyloses that white oak is suitable for making liquid-tight barrels (tight cooperage stock). Red oak lacks these cells and cannot be used for liquid containers (it is classed as slack cooperage stock). This lack of tyloses makes red oak (See "V" Plate III) an easy wood to impregnate with preservative solutions, such as coal-tar-creosote.

Durable hardwoods as a rule have abundantly developed tyloses. Other factors such as chemical composition, rate of growth, and hardness, as well as the presence of tyloses, are however also significant in determining durability. Tyloses are abundantly developed in the following very durable woods: Black locust, catalpa, osage orange, mulberry, white oak, post oak (Plate IV) and red heart beech.*

In the species where tyloses are present in the heartwood, they are found more or less fully developed in the sapwood also. In the few outside annual rings where the sap is being conducted up the tree no tyloses are normally present. Tyloses may be said to act as a natural filler in wood. It is easier for a carpenter to finish white oak than red oak, for the tyloses in the white oak provide a natural filler to catch the stain and varnish. In the cases of penetrance treatments and the water-logging of wood tyloses act as a filler or stopper to check the entrance of liquids. In the same way they provide a barrier to the entrance of wood-destroying fungi, the organisms causing rot.

THE PROPERTIES OF WOOD IN RELATION TO ITS USES.

Chemical Composition.—In selecting species of wood for special uses it is important to consider their chemical constitution. Aside from the resins, tannins, and other special secretions peculiar to the different species of wood, the bulk of the wood substance is made up of compounds of carbon, hydrogen, and oxygen, which are chiefly in the form of celluloses and lignin. A compound which has a high cellulose content is well adapted to the production of a high yield of chemical pulp. In preparing a chemical pulp the individual fibers of the wood are separated by cooking the wood in a liquor which dissolves out the greater part of its lignin content. This

*See Jour. of Agric. Research, Mar. 25, 1914. Vol. I, No. 6. "Tyloses: Their Occurrence and Practical Significance in Some American Woods."

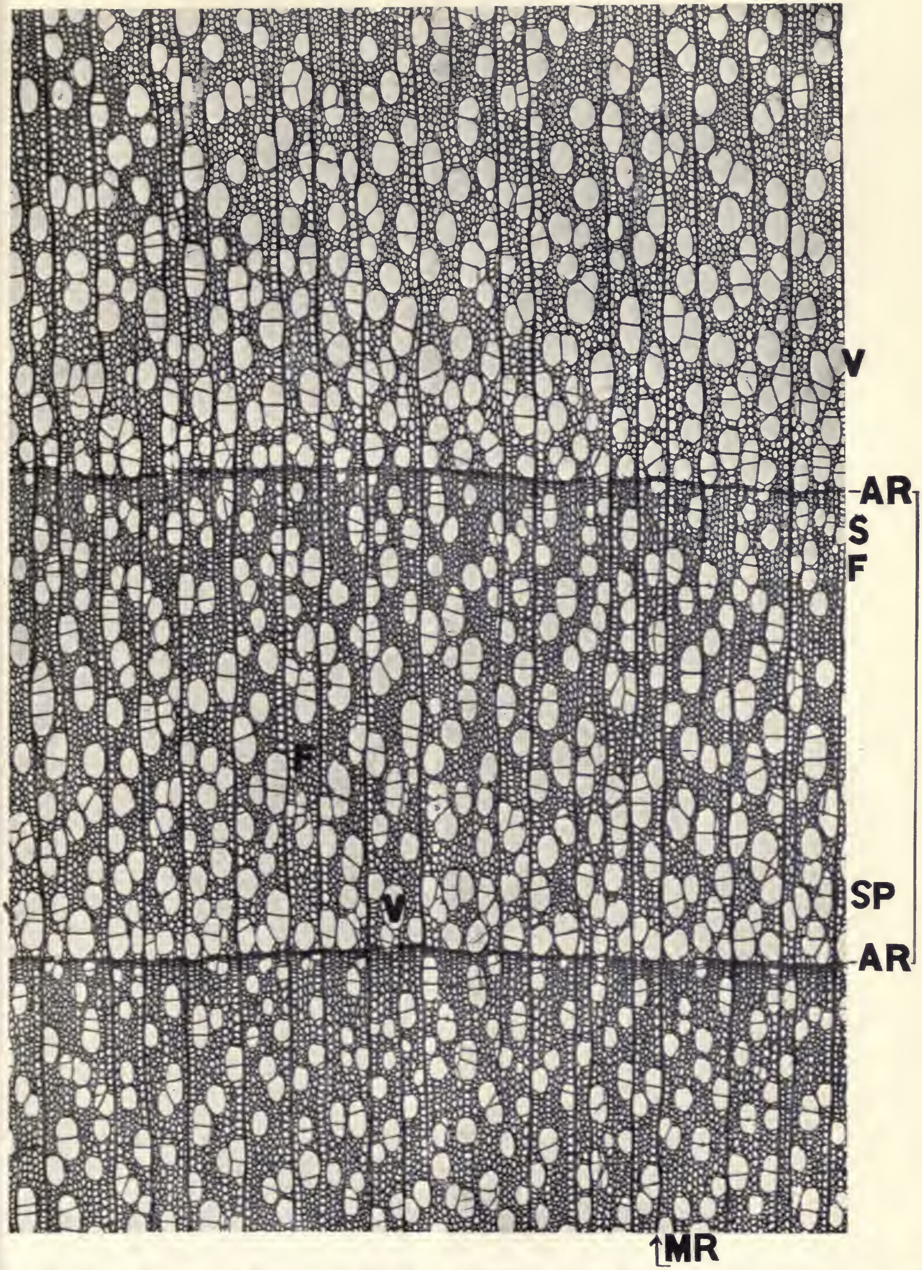


Plate II.—Cross Section of Poplar or Aspen. A Diffuse Porous Wood. AR. annual ring; SP, springwood; S, summerwood; F, fibers; MR, medullary rays; V, pores or vessels.

leaves the separated fibers somewhat thinner and weaker but with an almost pure cellulose composition, similar to that of cotton fibers. The less lignin present the easier it is to separate the fibers by cooking. The yield of pulp secured is correspondingly high if the wood has a high per cent of celluloses in its composition. The cellulose content of wood is also important in the production of ethyl or grain alcohol. Spruce is an example of a wood much used for this purpose. The celluloses present in the sawdust from such a wood are converted into sugar by treatment with acids. The solution obtained is then neutralized and the sugar is fermented with yeast, just as in the case of the preparation of ethyl alcohol from corn or other grains. It has been found that woods with a high lignin content give an especially good yield of wood or methyl alcohol in the process of destructive distillation. Such material as tops, slabs and edgings are used for this purpose. The products obtained from wood in this way are methyl alcohol (methanol), acetic acid, and charcoal. The species which have thus far been most successfully used for the manufacture of these products are beech, birch, and maple.

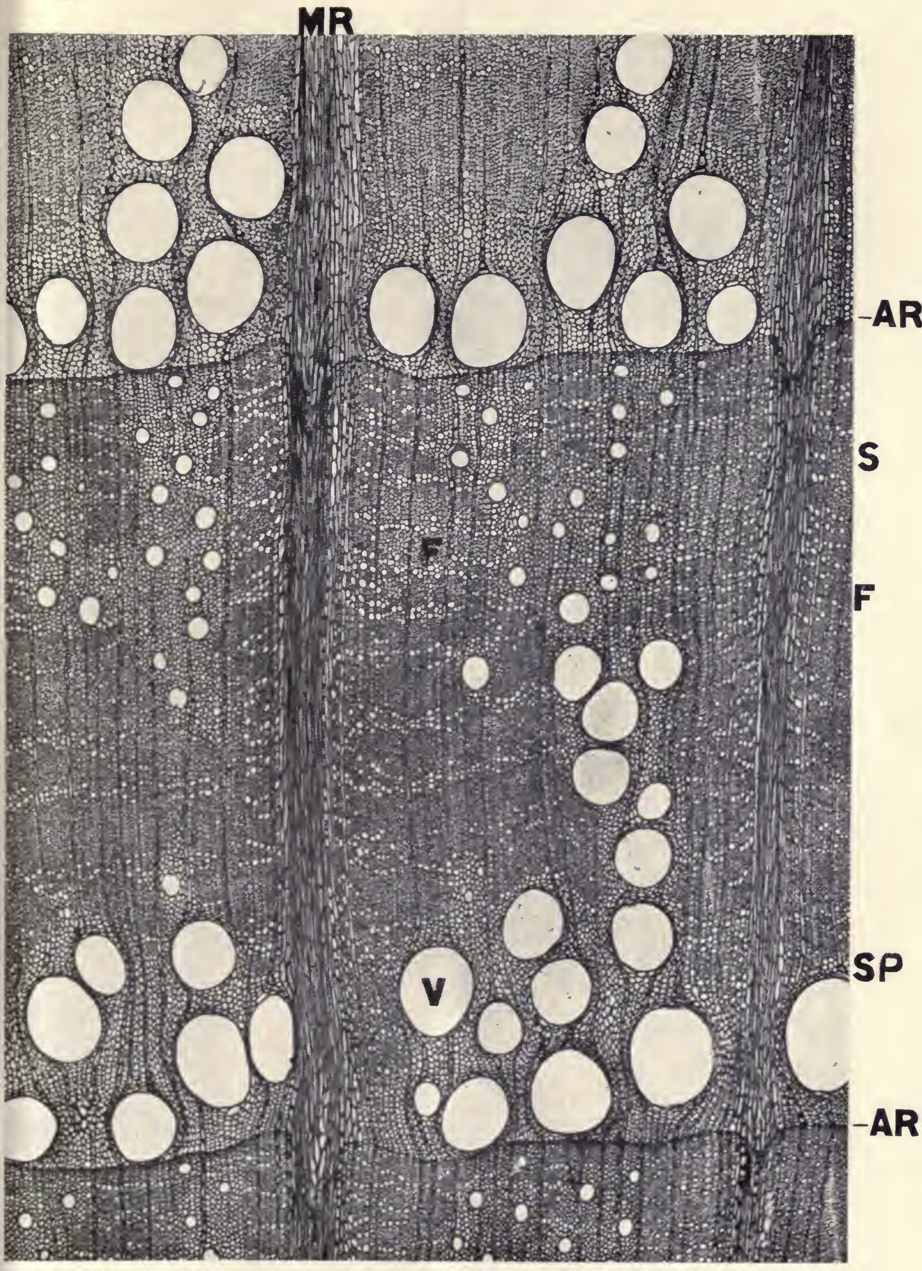
Physical Properties.—The structure and mechanical properties, such as strength, hardness and toughness, determine the suitability of wood for particular uses. The density or weight of the wood bears a direct relation to its strength. This depends upon the kind of elements present and the way in which they are arranged. Poplar (Plate II) and willow have many large open pores and relatively thin walled cells. Consequently, they are weak as compared with oak (Plate III) or black locust which have fewer large pores and many thick walled fibers ("f" Plate III and IV). It has been found that the density of wood substance in different species of trees may, for practical purposes, be considered as uniform with a value of 1.54*, yet the wood substance is so arranged in the different species that the unoccupied space in a block may often be from two-fifths to four-fifths of its volume. The arrangement of the wood elements under these circumstances may be compared with that of the cells in a honeycomb.

The openness of the pores and the uniformity of the structure are of great assistance in drying a wood. For this reason white pine, spruce and birch are easier to dry than oak. Water is contained in wood in two ways,—as free water in the cell cavities and as more or less closely combined water within the cell walls themselves. It is a relatively easy matter to dry out the water present in the cell cavities but as soon as an attempt is made to remove the water within the cell walls, shrinkage or warping begins to take place.

Trade Prejudices.—Trade prejudices which are maintained with surprising persistence sometimes hinder and sometimes apparently assist the utilization of a wood.

It has been found that many of the soft woods, such as tamarack, hemlock, balsam, and jack pine, may be used for making ground wood pulp for newspaper and fiber board stock. Some of these woods do not produce a news sheet that is as white as that

*See Journal of Agricultural Research, September 21, 1914, Vol. II, No. 6. The Density of Wood Substance and the Porosity of Wood—by Frederick Dunlap.



te III.—Cross Section of Red Oak. A Ring Porous Wood. AR, annual ring; SP, springwood (la open pores); S, summerwood; F, fibers; MR, wide medullary ray (silver grain); V, pores or vessels obtained from spruce. The slight degree of difference in color would not, however, interfere with the legibility of the printed words and the average reader would probably not notice the difference, yet the prejudice remains.

It is a well known fact that the sale of small cream cheeses is better when they are exhibited in white basswood boxes than when in pasteboard or other containers.

Hickory is one of the most important American woods. It is remarkable because it possesses to such a degree the combined properties of hardness, weight, stiffness, and toughness. The hickory wagon spokes and rims have made possible the American type of spring wagon with its superior lightness and strength. 65 per cent of the hickory cut is made into vehicle stock and handles. Approximately one-half of this is used for spokes for wagon and automobile wheels. The hickory handle has helped to make the American axe known all over the world. It has been found in the intensive studies of this wood made by the Forest Service that the red heartwood of hickory, which was once largely wasted, is fully as valuable for handles, etc., as the white hickory. The trade prejudice in favor of the white hickory is being gradually overcome. This means a closer utilization of this valuable wood. A significant step in this line is the adoption by the United States Navy Department of a hickory handle specification which admits red hickory on the same terms as white. A structural feature which influences the strength of hickory to a marked degree is the width of the annual rings. Slow growth material of this species is frequently brash and weak, due to the fact that when a ring is narrow the porous structure is developed at the expense of the fiberous portion of the ring which gives the strength to the wood.

Grain and Texture.—The terms "grain" and "texture" are often confused and misunderstood in present usage. The distinctive application of each has been well given as follows*:

> "Grain is a general term used in reference to the arrangement and direction of the wood elements and to the relative width of the growth rings. To have specific meaning it is essential that it be qualified. *Coarse grain applies to woods of rapid growth, that is, it denotes wide rings; fine grain to woods of slow growth.* Straight grain as applied to a tree occurs when the wood elements are parallel to the axis of growth." (The pine in Plate I has a finer grain than the oak in Plate III because it shows three complete annual rings to the one shown in the oak.)
>
> "Texture is a term which refers to the relative size, quality, or fineness of the elements. Like grain it requires qualifying adjectives to attain specific meaning. The most common attributes of texture are fineness and coarseness; evenness and unevenness. *Coarse texture applies to woods with many large elements* (See Plate III Oak) or the average size of which is large. For example, chestnut and sequoia. In fine texture the opposite condition prevails, as in red cedar and poplar. (Plate II.) Even texture or uniform texture are terms used to describe woods whose elements exhibit little variation in size, for ex-

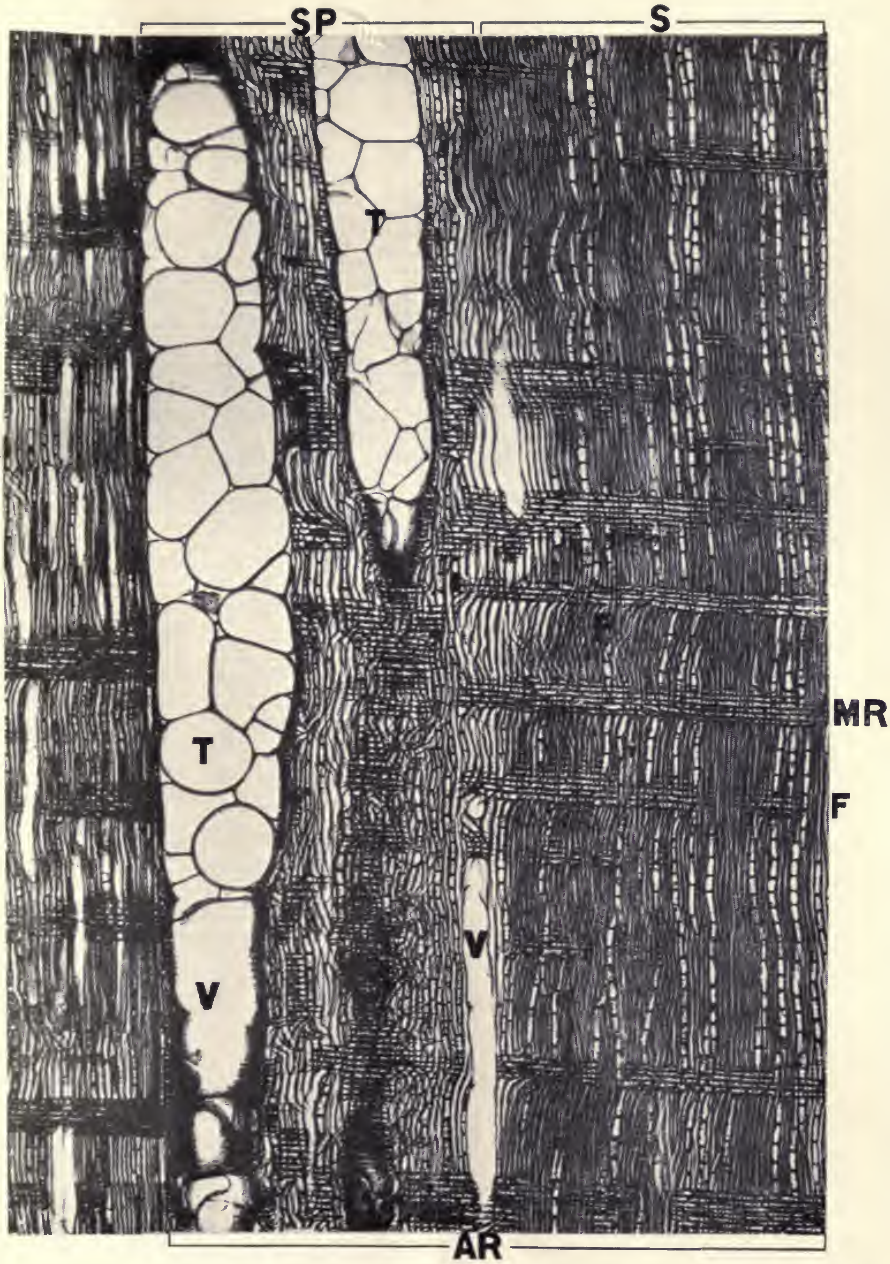


Plate IV.—Radial Section (Quarter Sawed) White Oak. A Ring Porous Wood. T, tyloses (completely closing pores or vessels); AR, annual ring; Sp, springwood; S, summerwood; F, fibers; MR, medullary ray; V, pores or vessels.

ample, cedar or poplar. (Plate II.) Uneven texture applies to the opposite condition such as is common in all prominently ring porous woods (for example oak (Plate III), elm and ash), and in other woods with decided differences between early and late wood (for example longleaf pine (Plate I) and Douglas fir). The distinctions as above expressed will obviate the difficulty resulting from the attempt to make the term "grain" too comprehensive."

CONCLUSION.

Approximately 52,800,000,000 board feet of wood are cut annually in the United States. This is enough to make a board walk two inches **thick** and five feet wide which would reach approximately forty times around the earth at the equator. The annual cut of wood is estimated to be three times the amount of the annual growth of the forests. A better knowledge of wood is necessary to insure a closer and more advantageous utilization of the trees cut. This must be brought about by the widespread co-operation of all those interested in forest products whether land owners, lumbermen, or users of the hundred and one commodities, from gunpowder to silk neckties, which are prepared from wood. A general knowledge of the structure of wood is of great importance. A thorough knowledge of its minute structure is of fundamental significance in the solution of the problems which are continually arising as the work of better utilization progresses. The "open sesame" to this knowledge is found in the use of two commonplace instruments,—the "jack-knife" and the "reading glass" or small hand lens. Highly perfected modifications of these which greatly assist the more careful and minute study of wood structure, are the microtome, which, by means of a very sharp razor, cuts sections of wood one-five-thousandths of an inch in thickness, and the microscope by which these sections may be seen greatly magnified in size.

It is like opening a closed book to read the history of the life processes of the tree from these thin transparent sections where it is possible to look through a single layer of the elements or cells which compose the wood. It often seems that the book is as difficult to understand as if it were written in a foreign language, but by dint of study and experiment much of the meaning and the relationships of the structural elements has been made clear and this information is fast being made available for all. This study reveals not only the wonderful perfection and the beauty of the once living tissue so useful to mankind after the tree's life is over, but it also makes apparent the underlying reasons for the behavior of the wood substance. On the results of such scientific and thorough study it is possible to lay the foundation for the conservation or, in other words, the efficient practical utilization of our forest resources.

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*See S. J. Record's "Economic Woods of the United States," J. Wiley & Sons, Publishers.